ORIGINATOR Director, Bureau of Highway Development		PROCEDURE 13-30-10
CHAPTER 13	Drainage	
SECTION 30	Channels and Road Ditches	
SUBJECT 10	Hydraulic Design of Open Channels	

This procedure presents the theory, design criteria, basic equations, and design procedures necessary to hydraulically design open channels.When designing open channels, the designer must be knowledgeable about the types of flow channel design characteristics and the basic hydraulic equations.

With this background information, the designer may design stable channels through application of the flexible lining criteria and design techniques discussed in this procedure. The design techniques along with example problems presented in this procedure are:

1. Flexible Lining Design
2. Steep Side Slope Protection
3. Bend Protection Design

In addition, water surface profiles for specific channels with varying hydraulic characteristics may be computed as described under "Water Surface Profiles," HEC-2. (See Procedure 13-20-1 for additional information)

Types of Flow

Steady Flow and Unsteady Flow: Time is the criterion. The flow at any cross section is said to be steady if the velocity does not vary in magnitude or direction with time; and, conversely, the flow is called unsteady if the velocity varies with time. In most open channel flow problems, flow conditions are studied under steady flow conditions only.

Uniform Flow and Varied Flow: Space is the criterion. Flow is said to be uniform when the depth of flow and the mean velocities are the same at successive cross sections in any reach. Uniform flow may only occur in a channel with a constant cross section. Varied flow occurs in reaches with uniform or varying cross sections affected by other controls or its own changing shape, which produce accelerated flow or backwater.

Although steady, uniform flow rarely occurs in natural streams and constructed channels, it is usually assumed as a check point for most open channel design problems.

Laminar Flow and Turbulent Flow: In laminar flow the water particles appear to move in streamlines or smooth layers, while in turbulent flow the water particles move in irregular paths that are neither smooth nor fixed but as a whole represent the forward motion of the entire stream. In general, all practical open channel flow problems exhibit turbulent flow.

Critical Flow: Critical flow occurs in an open channel when the specific energy (sum of depth and velocity head) is a minimum. In addition, critical flow occurs when the channel slope is at a specific slope, which is called the critical slope. When the channel slope is flatter than the critical slope (mild slope), the flow is subcritical. Conversely, when the channel slope is steeper than the critical slope (steep slope), the flow is supercritical. Flow at critical depth is unstable and excessive action or undulations of the water surface may occur. Therefore, when designing artificial channels, the following region of instability should be avoided: 0.9 (critical depth) < flow depth < 1.1 (critical depth). (5)

Design Characteristics

Inflow from the Sides: Channels that intercept surface flow from the sides must incorporate into their design the criteria that follow:

1. The lining shall be carried to an elevation slightly below the ground level.
2. A cut-off wall must be placed at the top of the lining to prevent undermining.
3. Pipes discharging into the channel shall be flush with the channel lining.

Drainage: If hydrostatic pressure is foreseen, both weep holes and a subsurface drainage system behind the sidewalls are required.

Bulking: At supercritical velocities, air entrainment occurs causing increases in the depth of flow (bulking effect). With concrete-lined channels, the normal depth of flow with a bulking condition can be determined by setting Manning's "n" equal to 0.018 instead of 0.014. For other lining types, multiply the n values given in Figure 1, Procedure 13-25-35, by 1.3.

Freeboard: The channel lining should be extended above the design water surface where waves and overflow may cause damage. For a guide to freeboard heights, the designer is referred to the Soil Conservation Service guide that follows:

Guide to Freeboard Height

Channel Shape	Subcritical Flow	Supercritical Flow
Rectangular	0.1 H_e	0.20 d
Trapezoidal	0.2 H_e	0.25 d

Note: H_e = energy head
d = depth of flow in a straight alignment

Random waves occur when the flow is near critical depth. When the channel slope is between 0.7 S_c and 1.3 S_c, the Soil Conservation Service recommends adding to the above freeboards an allowance for waves based upon the following formula:

$$\mathbf{H_w = 0.25\, d_c\ [1 - 11.1\, (S/S_c - 1)^2]}$$

where:

H_w = height of wave
d_c = critical depth
S = slope of channel
S_c = critical slope

Superelevation: Subcritical flow around a bend in an open channel causes the water to rise on the outside of the bend and thus an extra height of lining is required for protection. For supercritical flow, the water rises alternately on the outside and the inside of the bend, and hence the extra height of lining is required on both sides of the bend. For these extra heights, the designer is referred to the Soil Conservation Service formulas that follow:

Rectangular Channels

Subcritical Flow: $$H_s = \frac{3V^2 b}{4gr}$$

Supercritical Flow: $$H_s = \frac{1.2V^2 b}{gr}$$

$$\theta = [\cos^{-1}(\frac{r - 0.5b}{r + 0.5b}\cos B)] - B$$

<u>Trapezoidal Channels</u>

Subcritical Flow: $H_s = \dfrac{V^2(b + 2Kd)}{2(gr - 2KV^2)}$

Supercritical Flow: $H_s = \dfrac{V^2(b + 2Kd)}{(gr - 2KV^2)}$

where:

H_s = maximum height of water surface above depth d
V = mean velocity for the flow at the curve entrance
b = bottom width of rectangular or trapezoidal channel
g = acceleration of gravity (32.2 ft/s^2 or 9.80 m/s^2)
r = radius of channel center line
K = cotangent of bank slope
d = depth of flow for straight alignment at entrance to curve
Q = central angle of curve from P.C. to point of beginning of zone of maximum depth, in degrees
B = wave angle in degrees, defined as: sin B = $(gd)^{0.5}$/V

<u>Design Flow Rate</u>: Procedure 13-10-1, Figure 1, lists the design flow rate for roadside and median ditches as having a 25-year recurrence interval. Designing ditches to preclude erosion during the 25-year runoff would produce very expensive ditches. The Soil Conservation Service designs ditches for a 10-year recurrence interval runoff. Therefore, ditches should be designed to minimize the erosion potential with a 10-year runoff while still providing enough ditch capacity for a 25-year runoff.

If the permanent lining is to be a vegetative lining and a temporary lining is to be used during the establishment period, the mean annual flood (2.33-year recurrence interval) should be used for the design of the temporary lining. This is because the temporary lining is only required for a short period of time, and if the lining is damaged, repairs are usually inexpensive.

<u>Channel Geometry</u>: After the maximum permissible depth of flow has been defined, it is necessary to determine the amount of flow a specific channel geometry will convey. The Department of Transportation uses triangular shaped channels for roadway side ditches and median ditches, and trapezoidal shaped channels for channel changes.

<u>Channel Bends</u>: The increased shear stresses created by flow around a bend may produce scour that would not occur in straight channel reaches. To preclude the scour, it may be necessary to increase the rock riprap size or use a different lining material in the bend.

<u>Channel Side Slopes</u>: All drainage ditches should be designed with 3:1 or flatter sideslopes for purposes of safety, construction, maintenance, and erosion resistance.

For vegetative-lined channels with slopes steeper than 3:1, the design may not be valid because the design charts are based on tests of channels with 3:1 slopes.

For riprap-lined channels with side slopes steeper than 3:1, the stones on the sides may be dislodged by velocity and gravitational effects before the channel bottom is disturbed.

H.E.C. #15, "Design of Stable Channels with Flexible Linings,"(1) contains a method for designing rock riprap ditches with slopes steeper than 3:1.

For purposes of preliminary plans, Figure 1 may be used to determine the type of riprap treatment required for various combinations of side slope and channel flow velocities.

Hydraulic Resistance: For rock riprap, Manning's n may be used to model the hydraulic resistance. The Manning n value for rock riprap varies with mean stone size, as follows; using the Anderson Equation

$$n = 0.0395\ D_{50}^{(1/6)}$$

Vegetative linings are classified as Retardance A, B, C, D, or E according to a certain group of grasses of given lengths as defined by the Soil Conservation Service. Retardance A refers to grasses of high hydraulic resistance while Retardance E refers to grasses of low hydraulic resistance. There is a curve of Manning's n versus the product of VR, velocity and hydraulic radius, according to Figure 2, for each vegetal retardance. Generally, the grasses used for roadway ditches exhibit Retardance C in the summer and Retardance D in the spring. Therefore, the erodibility of the channel should be designed with Retardance D and the capacity of the channel should be checked with Retardance C.

It is possible that a ditch designed for Retardance C (6"-8" grass height) actually operates at a worse retardance condition (i.e., Retardance D) because of continual cutting to four inches or less by the local maintenance Staff. Therefore, the ditch should be designed for the typical maintenance cutting height (or worse condition); and if this is not possible, then the Design and Maintenance Sections should mutually agree upon an appropriate grass cutting height.

Design Computations

Continuity Equation: The discharge at any channel section is expressed as:

$$\mathbf{Q = VA}$$

where:

V = mean velocity

A = cross-sectional flow area perpendicular to the flow direction

For a continuous steady flow, the discharge along the channel reach is constant and expressed as:

$$\mathbf{Q = V_1\ A_1 = V_2\ A_2 = ...}$$

where the subscripts designate different channel sections

Manning's Equation: With an assumption of steady, uniform flow, flow velocities are computed by Manning's Equation, which is:

$$V = (1.49/n)\ R^{2/3}\ S^{1/2}$$

where:

V = mean velocity in fps

n = Manning's coefficient of channel roughness

R = the hydraulic radius in feet

S = slope of the energy grade line

In addition,

$$\mathbf{R = A/W.P.}$$

where:

A = cross-sectional area of the water in square feet

W.P. = wetted perimeter in feet

Commonly accepted values of Manning's roughness coefficient (n) based on materials and workmanship are given in Figure 1, Procedure 13-25-35.

Manning's Equation can be solved for rectangular channels, trapezoidal channels, and circular pipes with the aid of charts contained in Procedure 13-25-35. Additional charts for the solution of regularly shaped section can be found in references (2) and (3).

Solutions for odd shaped channels can be obtained by a trial and error method involving the equation or by using the nomograph in Figure 2, Procedure 13-25-35.

Bernoulli's Equation: The total energy in foot-pounds per pound of water may be expressed as the total head in feet of water, which is equal to the sum of the elevation above a datum, the pressure head, and the velocity head. See Figure 3 for a graphical depiction of the following concepts and equations.

The total head H at section A is written as follows:

$$\mathbf{H = z_A + d_A + (V_A^2/2g)}$$

where:

z_A = elevation of point A above an arbitrary datum in feet.

d_A = depth of flow in feet.

V_A = average velocity in ft/sec

Every streamline passing through a channel cross section will have a different velocity head because of the non-uniform velocity distribution in actual flow situations. Therefore, the velocity head determined from the mean velocity must be multiplied by an energy coefficient µ Thus, the total energy at section A is:

$$H = z_A + d_A + \mu\,(V_A^2/2g)$$

By the principle of conservation of energy, the total energy head at the upstream section A should be equal to the total energy head at the downstream section B plus the loss of energy h_f between the two sections, or:

$$z_A+d_A+\mu_A(V_A^2/2g)=z_B+d_B+\mu_B(V_B^2/2g)+h_f$$

When $\mu_A = \mu_B = 1$ and $h_f = 0$, then the above equation becomes:

$$z_A + d_A + (V_A^2/2g) = z_B + d_B + (V_B^2/2g)$$

which is the well-known Bernoulli Energy Equation.

The Bernoulli Energy Equation in conjunction with the Manning Equation can be used as the direct step method to determine the length of a channel reach with end sections of known parameters, or as the standard step method to determine the depth at the next upstream or downstream section when the parameters of the initial section and the distance between the sections are known. The methodology for applying these methods can be obtained from Ven Te Chow, Ph.D., "Open-Channel Hydraulics, McGraw-Hill Book Company, 1959.(4)

Design of Stable Channels with Flexible Linings

Unlined Channels: As a general rule, wet channels should not be lined unless warranted. Recommended permissible velocities for unlined channels are as shown in Figures 4 and 5. These figures are to be used as a guide, with local experience modifying the tabulated velocities.

Channel linings are considered necessary if the tabulated velocities or modified velocities based on local experience are exceeded.

Rigid Linings: The design of rigid linings, such as concrete, etc., can be accomplished by using Manning's formula to determine the required dimension of several different channel shapes. Since there is no erosion, naturally there is no maximum permissible velocity. The solution of Manning's Equation has been discussed previously in this procedure.

The advantages and disadvantages of rigid lining are as follows:

Advantages	Disadvantages
1. Large capacity	1. Expensive to construct & maintain
2. Prevent erosion in steep or difficult channels	2. Unnatural appearance
3. May be constructed within a limited right of way	3. Prevent or reduce natural infiltration
4. Underlaying soil completely protected	4. Sour at downstream end
	5. Linings may be destroyed by undercutting, channel head cutting, or hydrostatic pressure

Flexible Linings: The flexible linings covered in this discussion are temporary linings, vegetative linings, and rock riprap linings.

The advantages and disadvantages of flexible linings are as follows:

Advantages	Disadvantages
1. Cheaper than rigid	1. Limited flow depth because of erosion
2. Self-healing	2. Low capacity
3. Permit infiltration and exfiltration	3. Requires more right-of-way than rigid linings
4. Natural appearance	4. Riprap may be unavailable
5. Provide a filtering media for runoff contaminants	5 May not be able to establish vegetation
6. Lower velocity	

This discussion will cover only HEC #15,(1) "Design of Stable Channels with Flexible Linings."

Temporary Linings

Temporary linings are used to prevent erosion until permanent vegetation can be established by seeding.

The general requirements for erosion mat can be obtained from WisDOT's Interim Product Acceptability List.

For more information on temporary linings, see FDM Chapter 10 and HEC #15(1)

Vegetative Linings

All HEC #15 charts on vegetative linings were derived from the Soil Conservation Service (SCS) publication, "Handbook of Channel Design for Soil and Water Conservation."

From tests it has been established that sod works as well as established grass for erosion protection.

Rock Riprap Linings

HEC #15(1) contains design methods to design rock riprap channel linings, riprap on side slopes, channel protection in bends, and the granular filter blanket for riprap linings. It also contains criteria for plastic filter cloth design. The methods of HEC #15 should not be used for rapidly varied flow, such as occurs at bridge abutments.

The Wisconsin Department of Transportation's "Standard Specifications" states that 50 percent of the stone pieces for riprap and heavy riprap shall weigh more than 60 pounds (**27 kg**) and 150 pounds (**68 kg**), respectively This is translated into a D_{50} of 0.90 foot and 1.20 feet for riprap and heavy riprap, respectively.

Design Procedures

The design procedure in HEC #15 is based on the concept of maximum permissible tractive force. Methods for determining hydraulic resistance and permissible shear stress for specific linings are presented in the text. Nomographs are included for trapezoidal channels with uniform flow conditions. Nomographs are also provided for determining resistance characteristics for vegetation and permissible shear stress for soils. FHWA's HYDRAIN software package also has a channel stability program HYCHL which is based on HEC-15.

The remainder of this section outlines the design procedure for flexible channel linings and the design procedures for providing protection for channels with steep side slopes and channel bends. All the charts used here are listed in Hydraulic Engineering Circular #15.

Flexible Lining Design

For an example problem, see Figure 6 of this Procedure.

1. Determine: Q_{10} or Q_{25} - Permanent Lining
   $Q_{2.33}$ - Temporary Lining
2. Define channel shape and slope. Use 3:1 maximum side slopes if possible.
3. Select economical lining material.
4. Determine the permissible shear stress,
   t_p
5. Estimate flow depth range for non-vegetative linings or flow depth for vegetative linings, the channel shape, design discharge and slope.
6. Determine Manning's n-value for estimated flow depth.
   a. for non-vegetative linings, use Table 3, HEC-15.
   b. for vegetation:
      (1) Calculate the hydraulic radius, R. (Use Chart 4, HEC-15 for trapezoidal channels and appendix A, HEC-15 for other shapes.
      (2) Determine n from Chart 5, 6, 7, 8, or 9; HEC-15.
7. Calculate the flow depth, d, in the channel. (Chart 3, HEC-15 for trapezoidal channels)
8. Compare computed flow depth, d, with estimated flow depth, d_i. If d is outside the assumed range for non-vegetative linings or differs by more than 0.1 ft from d_i for vegetation, repeat steps 2 through 4 using d in place of d_i.
9. Calculate the shear stress, t_d if $t_d > t_p$, the lining is not acceptable, repeat steps 1 through 8.
   t_d = gds
   g = unit weight of water (62.4lb/ft 3)
   d = flow depth, ft.
   S = channel gradient, ft/ft.

The computation sheet shown in Figure 7 may be used to facilitate the above design procedure.

Steep Side Slope Protection Design

Rock riprap on channel side slopes steeper that 3:1 may be unstable; therefore, a special design is required for the riprap on the channel sides (for example problem, see Figure 8 of this procedure).

1. Determine the channel bottom rock size from the flexible lining design procedure.

2. From Chart 12, HEC #15, determine the angle of repose (q) for the bottom rock size and shape.
3. From Chart 13, H.E.C. #15, determine the ratio of maximum side shear to maximum bottom shear (K_1) for a trapezoidal channel, based on base width divided by depth of flow (B/d) and side slope (Z).
4. From Chart 14, H.E.C. #15, determine the ratio of critical shear on the side to critical shear on the channel bottom (K_2), based on side slope (Z) and the stone angle of repose (q).
5. The required D_{50} for the side slopes is:

   $(D_{50})sides = K_1/K_2\ (D_{50})bottom$

Bend Protection Design

In an open channel, flow around a bend produces centrifugal forces because of the change in flow direction. This causes a superelevation of the water surface. The water surface is higher at the outside of the bend that at the inside of the bend.

This superelevation can be estimated by the equation.

$$\_ = (V^2T)/gR_c$$

Where:

V = means velocity

T = surface width of the channel

g = gravitational acceleration, and

R_c = mean radius of the bend

Flow around a channel causes higher shear stress on the channel banks and bottom.

For a definition sketch see Figure 9. An example problem is shown in Figure 10 of this procedure.

Water Surface Profiles, HEC-2

In situations where it is necessary to determine the water surface profile of a channel with varying channel characteristics and flow rates, a program that analyzes gradually varied flow must be employed. One such computer program, entitled "Water Surface Profiles, HEC-2," was developed and first published by the U. S. Army Corps of Engineers in 1968. For further information on this subject, see the discussion in Procedure 13-20-1 under "Water Surface Profiles, (HEC-2) and (HEC-RAS)."

References

(1)U.S. Department of Transportation, Federal Highway Administration, Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular #15, Washington, D.C., 1986, 111 pp.

(2)Brater, E.F., and King, H.W., "Handbook of Hydraulics, Sixth Edition, McGraw-Hill, 1976.

(3)U.S. Department of Transportation, Federal Highway Administration, Design Charts for Open Channel Flow, Hydraulic Design Series #3, Washington, D.C., 1961, 105 pp.

(4)Chow, Ven Te, Ph.D., Open-Channel Hydraulics, McGraw-Hill Book Company, 1959.

1. (5)U.S. Department of Transportation, Federal Highway Administration, Design of Roadside Drainage Channels, Hydraulic Design Series (HDS) 4, Washington, D.C. 1965, 57 pp.

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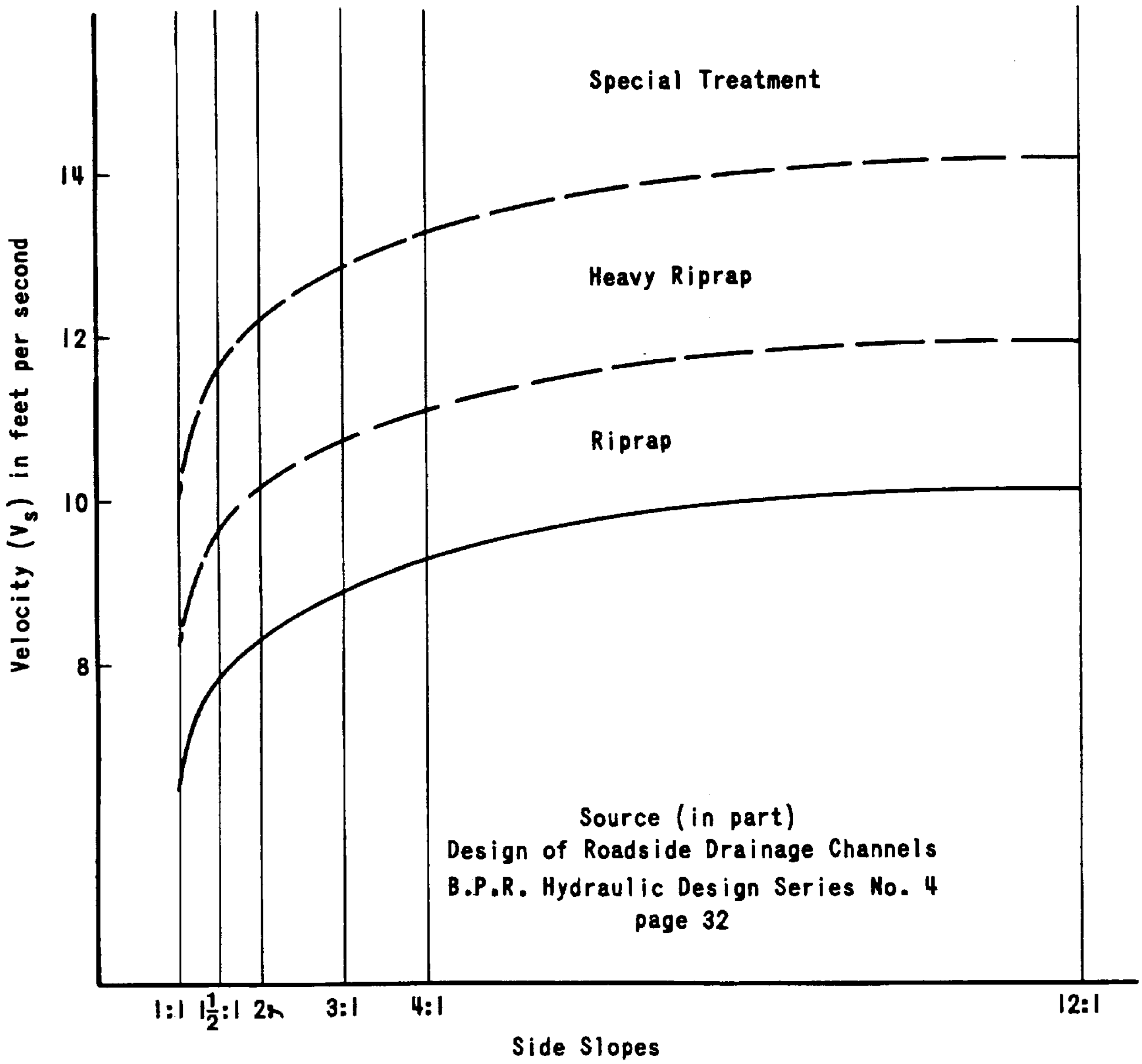
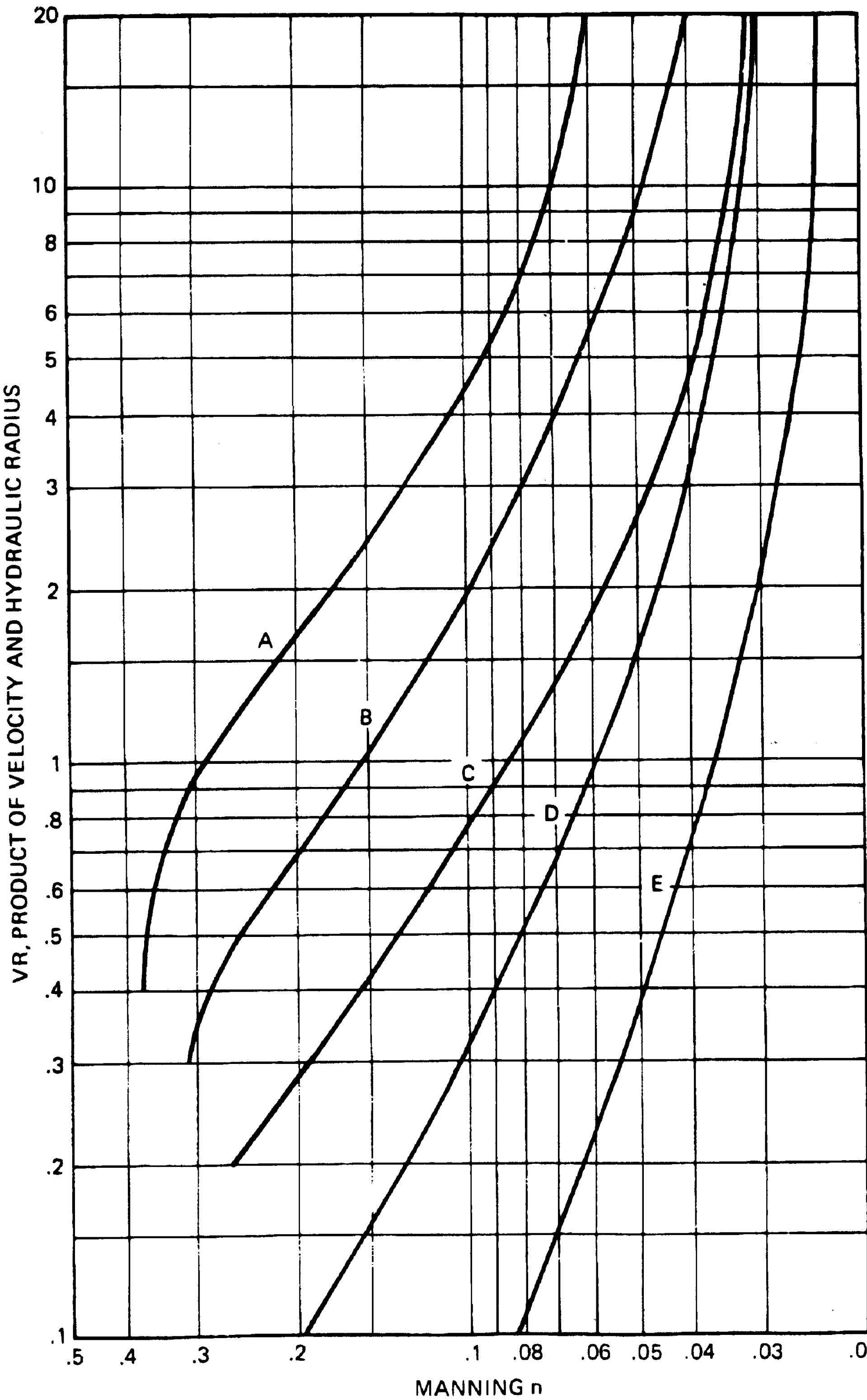
PERMISSIBLE VELOCITIES FOR RIPRAP LINED DITCHES



RIPRAP TREATMENT

Degrees Of Vegetal Retardance For Which Graphical Solutions Of The Manning Formula Have Been Prepared



FROM SCS "HANDBOOK OF CHANNEL DESIGN FOR SOIL AND WATER CONSERVATION"

Energy in Gradually Varied Open-Channel Flow

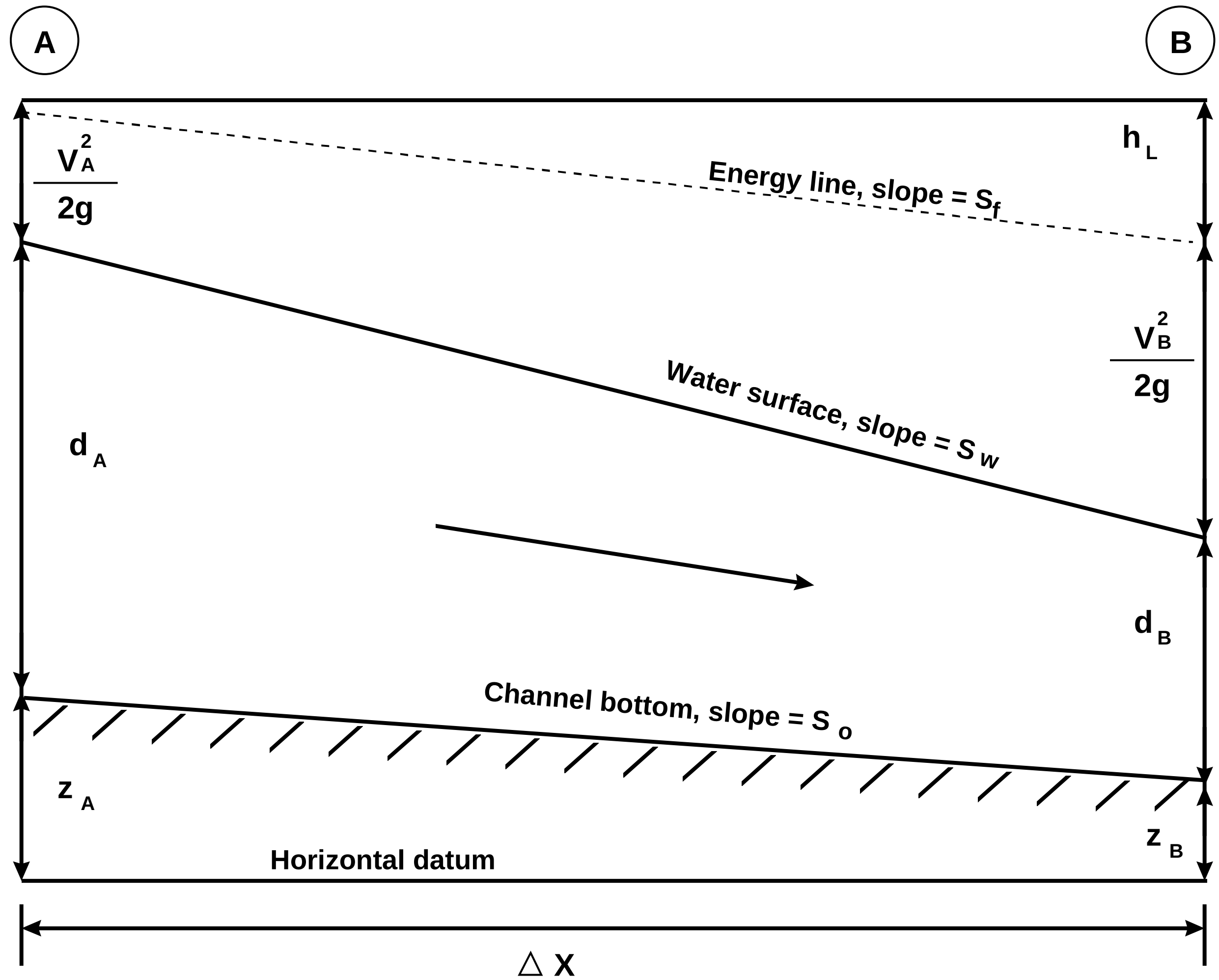


TABLE OF ALLOWABLE VELOCITIES

Median Ditches - Side Ditches - Secondary Ditches

Earth-No Vegetation	Maximum Allowable Velocities + *Clear Water	Earth with Vegetative Cover	Maximum Allowable Velocities +		
Soil Class or Lining		Type of Cover	Slope Range	Easily Eroded Soils	Erosion Resistant Soils
A-1 Fine Gravel	3.0	Well Established Grass--Bermuda Grass Sod	0-5 5-10 10+	6 5 4	8 7 6
A-2 Silty or Clayey Gravel and Sand	2.0 - 3.0	Meadow Type of Grass with Short Plaint Blades, Sod Forming such as Bluegrass, Smooth Brome, etc.	0-5 5-10 10+	5 4 3	7 6 5
A-3 Fine Sand	1.5	Grass Mixture, for Slopes <10%	0-5 5-10	4 3	5 4
A-4 Silt	1.5 - 2.5				
A-5 Firm Loam	2.5				
A-6 Clay	3.0 - 3.5	Bunch grasses, exposed soil between plants, vines and similar open cover as alfalfa, crabgrass, sudan grass, etc.	0-5	2.5	3.5
A-7 Colloidal Silts Stiff Clay	3.0-3.75				

BPR Highway Drainage Manual, January 1957

* Values will vary, usually slightly upward, for water carrying silt or sand.
+ Velocities given in ft/sec.

Channels at culvert outlets subjected to high velocities will usually develop a scoured hole which serves to dissipate the energy of the jet.

SUGGESTED TREATMENT WARRRANTS

Calculated Culvert Outlet Velocities	Channel Treatment Required
Max. Allowable (above) to 10 ft/sec	None, Other than SOD or Stabilization
10 ft/sec to 14 ft/sec	Dumped rock for a distance of 15 to 25 feet (**4.5 - 7.6 m**) beyond culvert
Greater that 14 ft/sec	Special treatment, such as an end sill, stilling basin or energy disapator

Recommended Permissible Velocities for Unlined Channels

Type of Material in Excavation Section	Permissible Velocity (Feet per Second)	
	Intermittent Flow	Sustained Flow
Fine Sand (Noncolloidal)	2.5	2.5
Sandy Loam (Noncolloidal)	2.5	2.5
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.5	3.5
Volcanic Ash	4.0	3.5
Fine Gravel	5.0	4.0
Stiff Clay (Colloidal)	6.0	4.5
Graded Material (Noncolloidal)		
Loam to Gravel	6.5	5.0
Silt to Loam	7.0	5.5
Gravel	7.5	6.0
Coarse Gravel	8.0	6.5
Gravel to Cobbles (Under 6 inches)	9.0	7.0
Gravel and Cobbles (Over 8 inches)	10.0	8.0

Source: California Highway Design Manual

Drainage Channel Lining Design Problem

Channel Lining Problem

Design a channel to carry the runoff from station 100+00 to station 125+00 on S 061-1 (27).

Design discharge = 15 cfs

Slope = 0.05 ft/ft

Channel is to be trapezoidal in shape with mild side slopes, (4:1) and bottom width, B = 4 ft. Maximum top width is 16 ft.

Available linings:

1. 6-inch Bermuda grass
2. 6-inch Rock riprap

Temporary Lining Problem

Design a temporary channel to carry the runoff from station 100=00 to station 125=00 on S 061-1 (27).

Design discharge = 5 cfs

Channel shape, slope and maximum top width defined in example above.

First check flow rate which bare soil will withstand to determine if temporary liner is necessary.

Available linings:

1. Jute net
2. Curled wood mat

Drainage Channel Lining Design

Designer: S.E.R. Date: 3-12-96

Project: S 061 - 1 (27)

Station: 100 + 00 To Station: 125 + 00

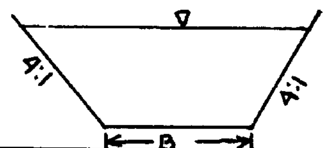
Drainage Area: 3 Acres

Design Flow: Q_{10} = 15 ft^3/sec

Design Flow for Temporary Lining : $Q_{2.33}$ = 5 ft^3/sec

Channel Slope (S): .05 ft/ft

Channel Description:



	Lining	Q	τ_p (1)	d_i (2)	R (3)	n (4)	d (5)	$\tau_d = \gamma dS$ (6)	Remarks
Temporary	Jute Net	5	.45	0-.5	—	.028	.204	.64	Unstable
Temporary	Curled Wood	5	1.55	0-.5	—	.066	.4	1.25	Stable
Permanent	non cohesive Bare Soil	15	.04	0-.5	—	.023	.38	1.18	Unstable
Permanent	6 inch Bermuda	15	1.00	.90	.60	.07	.68	2.12	Unstable
Permanent	6 inch Riprap	15	2.00	.5-2	—	.069	.64	1.99	Stable

The information from the notes below can be found in HEC-15, Drainage of Roadside Channels with Flexible Linings.

(1) Table 2
(2) For vegetation, estimate initial depth
For other liners, select range from table 3
(3) Vegetation only, chart 4 for trapezoidal channels
(4) For vegetation, charts 5-9
For other liners, table 3
(5) Normal depth, chart 3 (d must be in d_i range)

(6) τ_d must be $\leq \tau_p$

(7) Check for steep side slopes and channel bends

Drainage Channel Lining Design

Designer:______________________________ Date:__________________________________

Project:____

Station:______________________________ To Station:_____________________________

Drainage Area:____________________ Acres

Design Flow: $Q_{\_\_}$ = __________ ft^3/sec

Design Flow for Temporary Lining : $Q_{\_\_}$ = __________ ft^3/sec

Channel Slope (S):_______________ft/ft

Channel Description:

Lining	Q	τ_p (1)	d_i (2)	R (3)	n (4)	d (5)	$\tau_d = \gamma dS$ (6)	Remarks

The information from the notes below can be found in HEC-15, Drainage of Roadside Channels with Flexible Linings.

(1) Table 2
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(3) Vegetation only, chart 4 for trapezoidal channels
(4) For vegetation, charts 5-9
For other liners, table 3
(5) Normal depth, chart 3 (d must be in d_i range)

(6) τ_d must be $\leq \tau_p$

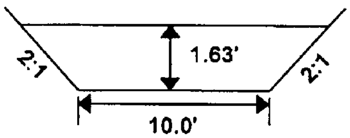
(7) Check for steep side slopes and channel bends

Design of Rock Riprap Linings for Steep Trapezoidal Channel Sides

Given a trapezoidal channel with a bottom width of 10 feet and 2:1 side slopes. The channel slope is 0.02 ft/ft. and the design discharge is 150 cfs. The mean stone size D_{50} ,in the bottom is 1.0 ft. The available stone is classified very rounded.

For the above dicharge, the normal depth of flow is 1.63 ft. What size stone should be placed on the sides?

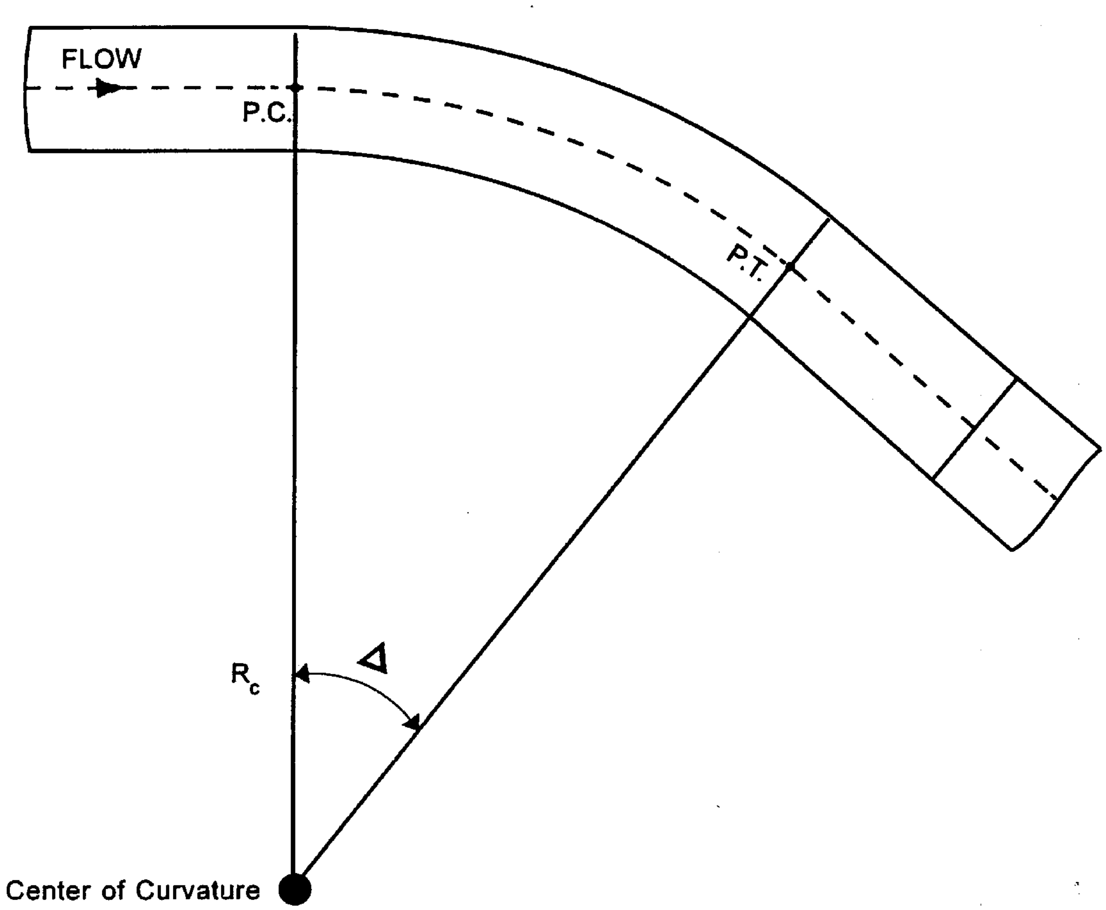
$$(D_{50})\text{sides} = \frac{K_1}{K_2} (D_{50})\text{bottom}$$



1. D_{50} = 1.0 ft. (in channel bottom)
2. From chart 12, H.E.C. No. 15; $\theta = 38.5°$
3. With $B/d = \frac{10.0}{1.63} = 6.14$, from chart 13, H.E.C. No. 15, $K_1 = 0.78$.
4. With $Z = 2$ and $\theta = 38.5°$ from chart 14, H.E.C. No. 15, $K_2 = 0.70$.
5. $(D_{50})\text{sides} = \frac{K_1}{K_2}(D_{50})\text{bottom}$

   $(D_{50})\text{sides} = \frac{0.78}{0.70} * (1.00) = 1.11'$

Therefore use riprap with a mean diameter of 14."



R_c = radius of curvature measured to middle of channel, ft.

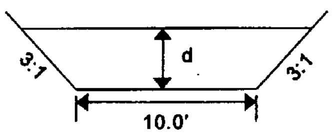
Δ = internal angle, degrees

Definition Sketch for Flow in Bends

Design of Rock Riprap for Flow of Bends

Given a trapezoidal channel with a bottom width of 10 feet and 3:1 side slopes. The channel slope is 0.02 ft/ft. and the design discharge is 150 cfs. The mean stone size D_{50} ,in the straight reach is 1.0 ft.

The channel has a bend with a 100ft. radius and an internal angle of 30 degrees. Determine if a 1 ft. stone size is adequate for the bend area.



1. from Manning's Equation, $d = 1.70'$

2. τ_p for riprap, 12 inch, $D_{50} = 4.00$ lb/ft^2 Table 2, HEC 15.

Shear stress in straight section:

3. $\tau_d = \gamma d S = 62.4(1.7)(.02) = 2.12$ lb/ft^2

for Channel Bends:

4. $K_b = 1.05$ from chart 10, HEC 15.

5. Calculate shear stress in the bend, τ_b

$\tau_b = K_b \tau_d = (1.05)(2.12) = 2.23$ $lb/ft^2 < 4$ lb/ft^2 O.K.

6. Calculate length of protection downstream of the bend using Chart 4 and Chart 11, HEC 15.

$L_p/R = 12$

$L_p = 9.7'$

7. Calculate the superelevation

$$S.E. = \frac{V^2 T}{g R_c} = \frac{(9.05^2)(20.2)}{(32.2)(100)} = .10$$